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# Vulnerability Assessment of Surface-to-Air Missile Systems

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## ABSTRACT.

The susceptibility of a surface-to-air missile system to surveillance and target acquisition sensors operating in the infrared wavebands of 3-5 and 8-12 µm has been analyzed by testing. The trials were carried out accordingly STANAG 4418 and AVTP Trial series 05, with and without camouflage systems installed. It is described the planning and execution of the tests, the equipment employed and the data analysis procedure. The effectiveness of the camouflage systems to reduce the thermal signature, has been assessed using the acceptance criteria established on STANAG 4418. Some examples are discussed.

## 1. INTRODUCTION.

The measurement of overall thermal radiation determines the energy level projected to a sensor for a given target position. This radiation makes it possible to detect and recognize vehicles at great distances, using IR sensors, like the ones used in thermal cameras, surveillance systems and missile heat seekers.

Infrared radiation is absorbed and scattered by the atmosphere. For that reason detection at tactically relevant ranges is possible only in the so-called “atmospheric windows”. Two of the most typical are the wavebands of 3-5 (short band) and 8-12 µm (long band), or sub-bands within the above ones. In these regions of the spectrum, the radiation reaching the sensor is due mainly to self-emission from the vehicle hot parts (except for a component of solar reflection in the short band). This allows that thermal imagers could work at day and night, and detection results from either a positive thermal contrast when the object emission is higher than its surroundings, or from a negative thermal contrast when the background emission is higher.

## 2. TARGET ACQUISITION.

The ability to detect, recognize or identify a vehicle by means of thermal imagers depends on a series of factors, among others:

- nature, size and activity of the vehicle,
- environment and background,
- performance of the imager.

The nature of the vehicle plays an important role in the recognition and identification tasks. Usually they are carried out looking for some characteristic feature of such vehicle (e. g. wheels in a truck, barrel in a cannon, tracks in a tank).

For a given imager and environmental conditions, the size of the vehicle determines the maximum range at which it can be detected, because is necessary to have at least two pixels for a 50% probability of detection (Johnson’s criteria). The activity of the vehicle has a strong impact on its thermal signature, increasing the thermal contrast of certain parts. For example, a truck with the engine running presents a higher contrast in the exhaust system and in the surfaces covering the engine, if the vehicle has recently moved the tires threads are hotter, if a cannon has been shooting, its barrel is hotter too. In these cases detection or recognition of the target is easier.

Environment and background have great importance for target acquisition tasks. During daytime hours solar heating can significantly increase the thermal signature. However, solar heating also increases the background thermal clutter; so, vehicle targets are often easier to detect during night time even though their thermal signature is lower in this condition.

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Given a particular set of target, environment and background, the performances of the thermal imager determine if any of the acquisition tasks are possible. The system should have a thermal sensitivity enough to detect temperature differences between target and background as low as possible, and provide the spatial resolution required for the specific task. Thermal sensitivity will limit detection range, while spatial resolution will limit recognition range. Spatial resolution must be higher for recognition than for detection, and for identification than for recognition. Surveillance systems usually have optics with two or three different focal lengths; so, they can perform detection tasks covering a wide area (field of view), and recognition or identification in narrower areas.

All of the above means that when planning a trial to characterize the susceptibility of a system, to surveillance and target acquisition sensors working in the infrared, it will be necessary to take into account the factors before mentioned.

## 3. TRIALS PLANNING.

The aim of this kind of trials is to collect a set of infrared images of the targets under study; so, after an appropriate analysis, the infrared signature of them could be characterized.

Because the shape of the targets is different for different positions relative to the imager, it is necessary to acquire images from several points of view around the target (minimum eight). This should be made installing the sensors in a fixed location, and moving the target as required. The elevation angle is also important, because surveillance systems are usually installed on board air platforms. To acquire top views of the target is not easy, specially for the larger ones; normally it is necessary to use wide field of view optics, and that means low spatial resolution. So, a reasonable solution is to put the imagers at a fixed elevation angle, representative of common surveillance systems.

If the target to be tested has some kind of camouflage system available, the trials should be carried out with and without the camouflage system installed, in order to assess its effectiveness.

The targets should be tested in a thermal state representative of operational conditions. For a vehicle this is done following a warming-up procedure (e. g. driving on a hard surface for 30 minutes clockwise and 30 minutes anti-clockwise). During daylight time the vehicle must be kept in the shade for at least 6 hours before warming-up, in order to avoid an inappropriately hot signature. If testing a power generator it must be running at an operational rate.

The trials should be repeated for different environments. Typical conditions are: clear summer's day, overcast day, clear night and overcast night. Measurements should not be made during rainfall or high wind speed. As it has been said before, the background also has a strong influence in target acquisition tasks. Because backgrounds are very different for each operational scenario, and experience seasonal changes, it is very difficult to carry out tests that cover all the possibilities. An alternate solution is to use a uniform background at a known temperature. In this way, it is possible to make comparisons between infrared signatures, associated to different vehicles and environments.

To acquire infrared images of the targets under analysis, the appropriate thermal imagers must be chosen. Ideally, they should be the same used in real threats. Because, normally, this is not possible, the following should be taken into account:

- the sensors must work in wavebands typical for thermal infrared (3-5 and 8-12 μm),
- sensitivity and spatial resolution must be representative of current threats.

The resolution over the target depends too, on the range at which the sensors are set up. It should be such that the target, in its largest dimension, fills the field of view. At least, the target must cover two times the Instantaneous Field of View.

It is convenient to use calibrated thermal imagers, in order to obtain temperature maps of the target surface. Although surveillance and target acquisition systems do not have that capability, is interesting to identify quantitatively the hot spots on the target; so, adequate methods for temperature reduction could be applied.

## 4. TRIALS EXECUTION.

The methodology explained above has been used to assess the vulnerability, in the thermal infrared, of a Spanish Army surface-to-air missile system.

The system consists of nine different targets, namely:

- Fire control unit.
- Missile launcher.
- Cannon.
- Launcher's power generator.
- Cannon's power generator.
- Truck 10 Tons.
- Truck 8 Tons.
- Truck 5 Tons.
- Light vehicle 1 Ton.

Camouflage nets for all the targets were available, and they were used in the tests. Measurements with the nets installed were made, for each target, immediately after the measurements without net; so, the thermal state of the vehicle was the same in both cases.

Before entering the measurement area, the vehicles followed a warming-up procedure as described in section three. The power generators were running at their operational rate.

The measurement area was a concrete surface with marks for the eight horizontal aspects, in which the vehicle was going to be tested (0°, 45°, 90°, 135°, 180°, 225°, 270°, 315°). Orientation was defined such that 0° is the left side of the vehicle, and aspect angle increases as the vehicle is rotated anti-clockwise, as viewed from the top.

The targets were placed under a sun shield to avoid direct sunlight during the measurements. A hessian screen, shielded from direct solar radiation was used as background, and its temperature was monitored during all the test.

Environmental conditions were clear summer's day, and clear night.

The thermal sensors were installed at a range of 60 meters, on a slightly elevated place.

Surface temperatures in ten selected points of the targets were measured by means of calibrated thermocouples. These data were used as a reference, for temperature maps recorded with the thermal imagers.

The equipment used was the following:

- Two calibrated thermal imagers Agema SWB (3-5 μm) and Agema LWB (8-12 μm).
- Digital recording unit.
- TV camera and video recorder.
- Laser rangefinder.

- Weather station ( with sensors for pressure, ambient temperature, humidity, solar irradiance, wind speed and direction).
- Datalogger and thermocouples K.
- Monitors.

## 5. DATA ANALYSIS.

Target acquisition in the thermal infrared can be made when one of the following conditions is met:

- Thermal contrast between target and background is higher than a given threshold.
- The target exhibits a textured appearance, with areas of constant temperature bigger than a specified size.

The first condition is important for detection tasks, because thermal imagers are able to sense small temperature differences from long ranges. The second one is specially meaningful for recognition, because man made objects usually have regular patterns that are difficult to find in natural backgrounds.

Processing of the thermal images for each target and condition, is necessary to obtain thermal contrast and textures. The procedure applied has been the following:

- For each pixel of the image the temperature difference with respect to average background is calculated.
- All the pixels on the target having temperature differences higher than a threshold are marked out, and the corresponding area calculated.
- Starting from the lowest temperature in the thermal image, a search for constant temperature areas is carried out. Because thermal resolution of the images is 1 °C (one digital value), differences of temperature between pixels of ±1 °C have been neglected.
- Areas of the target that meet the above condition are marked out.

## 6. RESULTS.

The results of the analysis applied to two of the targets tested are presented in figures 1 to 14.

Figures 1 and 2 show the importance of acquiring images from different points of view, in order to properly characterize the signature of a target. Figure 1 is a front view of a power generator. In that image no significant areas are seen. Figure 2 is a rear view of the same target. Although the geometrical shape of both images is nearly the same, in image 2 the engine and exhaust system are clearly displayed. These parts have a thermal contrast with respect to background, high enough to allow detection. In figure 3 is marked out in red, and evaluated, the corresponding area.

**Figure 1. Power generator. Front view.**

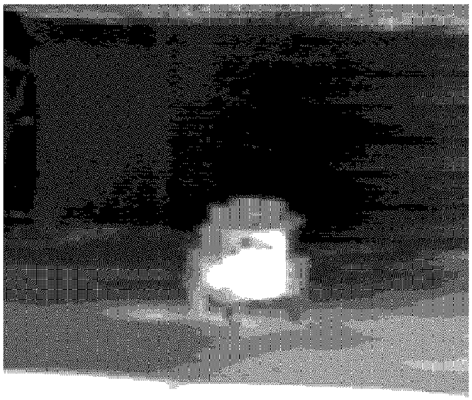

**Figure 2. Power generator. Rear view.**

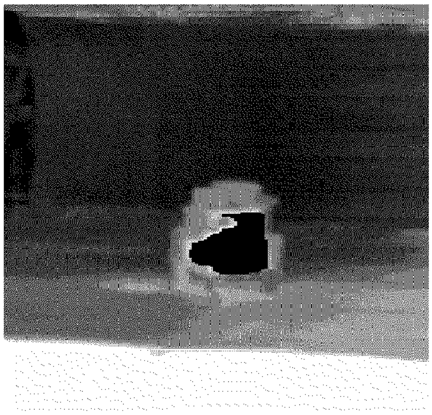

**Figure 3. Power generator.**
**Rear view. Pixels with thermal contrast above threshold, in red. A= 1.5 m².**

Figure 4 is a front view of the power generator with a camouflage net installed. The thermal contrast of this image is lower than that of figure 1; so, the net seems reduce the vulnerability of the power generator. Figure 5 is a rear view of the generator with the net installed. There is some improvement with respect to the case shown in figure 2, but the net is clearly insufficient to mask the exhaust system. So, detection of the target is still possible, even with this camouflage net installed. Figure 6 shows in red the high contrast area.

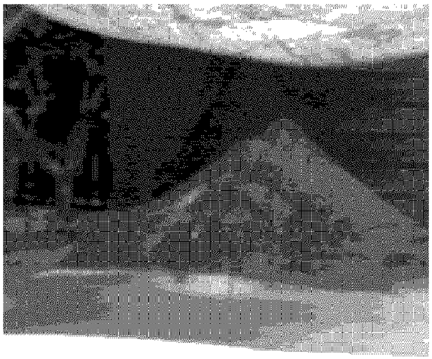

**Figure 4. Power generator. Front view. Camouflage net installed.**

Figure 5. Power generator. Rear view. Camouflage net installed.

Figure 6. Power generator. Rear view. Camouflage net installed.
Pixels with thermal contrast above threshold, in red. A= 0.5 m².

Figure 7 displays a left view of a truck in a day condition. Hot parts corresponding to the engine and the exhaust system are clearly viewed. These parts could allow detection, but not recognition, because their shape is not distinctive. However, a texture analysis reveals, areas of constant temperature having circular patterns. Figure 8 shows some of these areas in red. This allows recognition, because circles are typical of a wheeled vehicle like the one considered.

Figure 7. Truck. Left side view. Day condition.

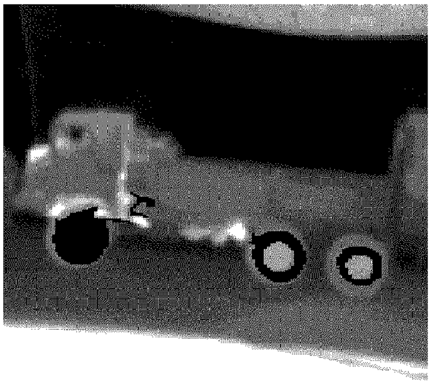

**Figure 8. Truck. Left side view.**
**Day condition. Areas of constant temperature, in red. A= 2.3 m².**

Figure 9 shows the same truck in a night condition. Circular patterns are visible as displayed in figure 10; so, recognition at night is possible.

**Figure 9. Truck. Left side view. Night condition.**

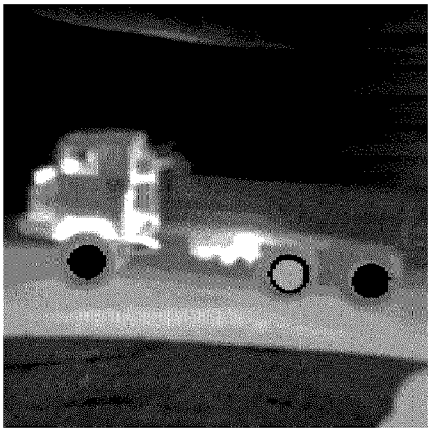

**Figure 10. Truck. Left side view.**
**Night condition. Areas of constant temperature, in red. A=1.1 m².**

Figures 11 to 14 show the truck at day and night with a camouflage net installed. Hot parts are still visible, but the texture analysis does not reveal characteristic shapes; so, recognition is not possible when the net is installed.

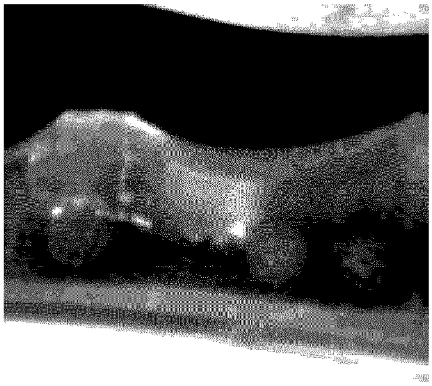

**Figure 11. Truck. Left side view. Day condition. Camouflage net installed.**

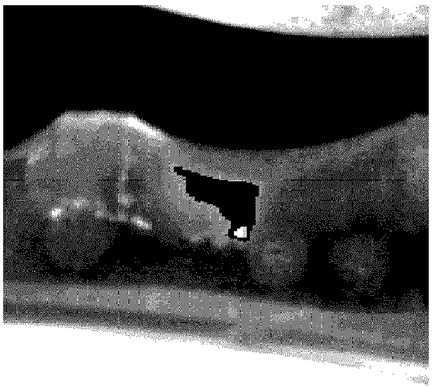

**Figure 12. Truck. Left side view. Day condition. Camouflage net installed. Areas of constant temperature, in red. A= 1 m².**

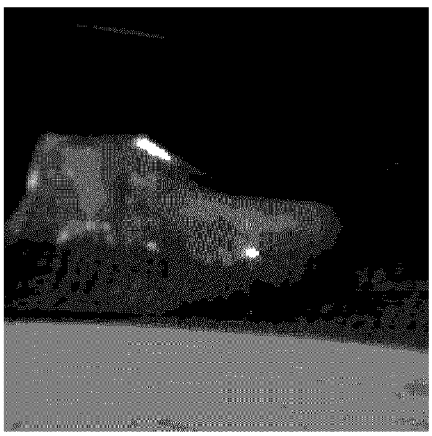

**Figure 13. Truck. Left side view. Night condition. Camouflage net installed.**

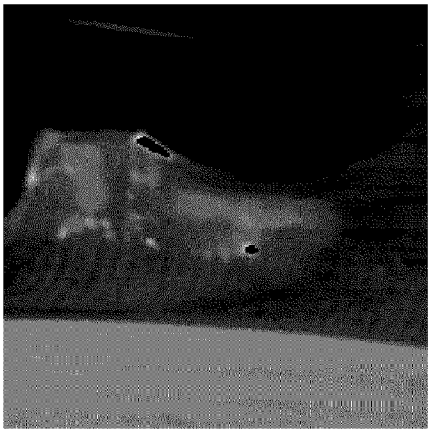

**Figure 14. Truck. Left side view. Night condition.**
**Camouflage net installed. Areas of constant temperature, in red. A= 0.2 m².**

## 7. CONCLUSIONS.

The susceptibility of a surface-to-air missile system to surveillance and target acquisition sensors operating in the infrared has been analyzed by testing.

To carry out a complete analysis factors like: waveband of interest, target orientation relative to the imager, thermal state of the target, environmental conditions and camouflage systems; must be considered.

Hot parts of the targets are clearly seen in the infrared, and could give place to detection at day or night conditions. This is specially true for certain orientations of the target.

Camouflage nets not always can mask hot parts; so, detection could be possible with the net installed.

Recognition of the target is made looking for characteristic patterns. These patterns are not necessarily associated to the hottest areas of the target. Camouflage nets give place to non regular patterns; so, they could be more effective to avoid recognition than detection.

## REFERENCES.

STANAG 4418 “Countersurveillance Requirements”. (NATO RESTRICTED).

STANAG 4319 “Countersurveillance Requirements for Future Main Battle Tanks. Infrared/Thermal Aspects”. (NATO RESTRICTED).

STANAG 4347 “Definition of Nominal Static Range Performance for Thermal Imaging Systems”.

AVTP Trial Series 05: Security from Detection.

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